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EMPIRICAL VOLUMEESTIMATION OF LANDSLIDE INDUCED BY SINGLE HEAVY RAINFALL EVENT AT SOUTHERN TAIWAN FROM PROJECTION AREA OF REMOTE SENSED IMAGERY

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ABSTRACT

The purpose of this study is to establish an empirical formula to calculate the heavy rainfall induces landslide volumes via areas derived from remote sensing imagery. Photogrammetry and LiDAR gather the post-event terrain data at southern Taiwan. Besides the precise LiDAR DEM, hillside image method by Single Imagery Similarity (SIS) also utilized to estimate the volume change of the landslide events triggered by single rainfall. Better estimating inaccuracies is founded while using the horizontal projection area instead of traditional landslide surficial area. The volume estimating equation of this study is $V=0.7604A^{1.2369}$, ($R^2=0.8901$) with horizontal projection area and $V=0.2422A^{1.2599}$, ($R^2=0.7384$)via surficial area. Deep-seated landslide triggered by single rainfall event is more likely to happen at landslide projection area large than 3000 m^2. We also found the coefficients in affecting the estimating volume via area of landslide induced by heavy rainfall is 15 times larger than regular rainfall event.

KEYWORDS: Landslide, Volume Estimate, Projection Area

INTRODUCTION

Landslide is either triggered by earthquake or rainfall or combination of both. Landslides play a major role causing considerable loss of lives and properties among all the nature hazards[Glade, 1998; Guzzetti et al., 1999].Landslide volume is the key information in determining the scale of event. Gathering the landslide volume change for each rainfall or earthquake event could establish the causing parameters and its associated weighting factor. The standard method of manipulative landslide volume change is to subtract the terrain dataprior and after the event. However, the high-resolution terrain data could be labor intensive and also expensive that makes the regular data acquisition becomes impossible. Therefore, we applied the SIS method [*Wang et al.*, 2014]with single remote sensed imagery to estimate the landslide volume change to supplement events that is not covered by the LiDAR mission.

MATERIALS AND METHODS

The analysis data set is taken at the Chishan and Laonong river watershed at southern Taiwan after the heavy rainfall of typhoon Morakot at 2009. Locations of newly landslides at these two watersheds are shown in Figure 1 and 2. The pre-event terrain data is produced by photogrammetry method with aerial stereo image at 2004. Aerial Light Detection and Ranging [*Arnadottir et al.*] offer 5 m intervals Digital Elevation Model (DEM) taken at 4 months after the. The rest of post-event landslide volume change is collected by SIS method with satellite image taken a week after the event. Changes of elevation at these two regions are shown in Figure 3 and 4. At first the surficial area of landslide is derived from the regions of newborn bare land at imagery. These images then be ortho-rectificated with pre-event DTM

thus to measure the horizontal projection area of individual landslide by Geographic Information System. There are 327 cases of new landslides within testing area that induced by this heavy rainfall. The volume change of this group has higher degree of accuracy than another 67 cases via SIS method; data and regress trend is shown in Figure 5. The landslide area and volume estimating equation of this study is as following:

$$V=0.2422A^{1.2599}, (R^2=0.7384) \text{ where A: surficial area} \quad \{1\}$$

$$V=0.7604A^{1.2369}, (R^2=0.8901) \text{ where A: horizontalprojection area} \quad \{2\}$$

Whit this formula we estimating the volume change of landslide according to individual areas at each newly developed landslide. Two types of area derived from equation 1 & 2 are listed in Figure 6 for comparison purpose. We found the biases between calculated results of these two statics trend are increased as the size of area enlarged. Since the $R^2$of equation 2 near to 0.9 then it is a prefer method in determining the size of landslide areas to calculate corresponding volume change. Simonett [1967] analysis 201 landslides in New Guinea and get $V=0.024A^{1.368}$, another estimation is $V=0.05\pm0.02A^{1.5}$ by Hovius et al. [1997].

In addition, equation 2 divides by area (A) to get the averaged depth of landslide:

$$\Delta h = 0.7604A^{0.2369} \quad \{3\}$$

Calculated average depth via these two equations is listed in Figure 7. Deep-seated landslide is defined as the depth exceed 5 m [*Petley and Allison*, 1997], it didn't occurred as often as the shallow landslide but the huge amount of volume change of such kind always create devastate damage. Form equation 3 we found the deep-seated landslide induced by single heavy rainfall event shall occurred at horizontal projection area of landslide exceed than 3000 m^2.

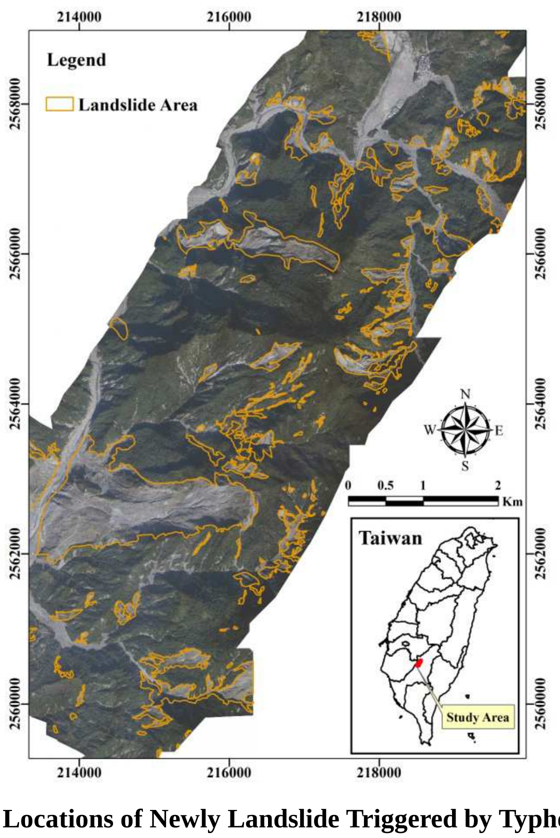

Figure 1: The Locations of Newly Landslide Triggered by Typhoon Morakot at the Chishan Watershed, Southern Taiwan

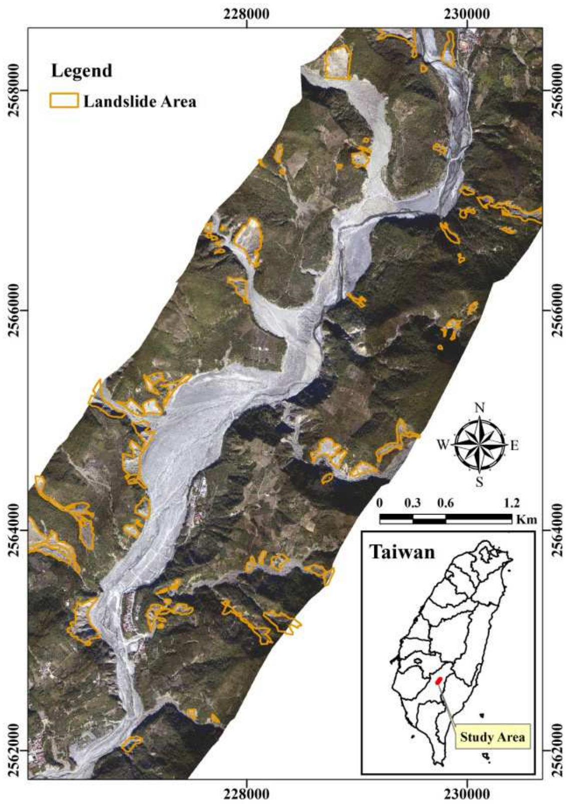

Figure 2: The Locations of Newly Landslide Triggered by Typhoon Morakot at the Laonong Watershed, Southern Taiwan

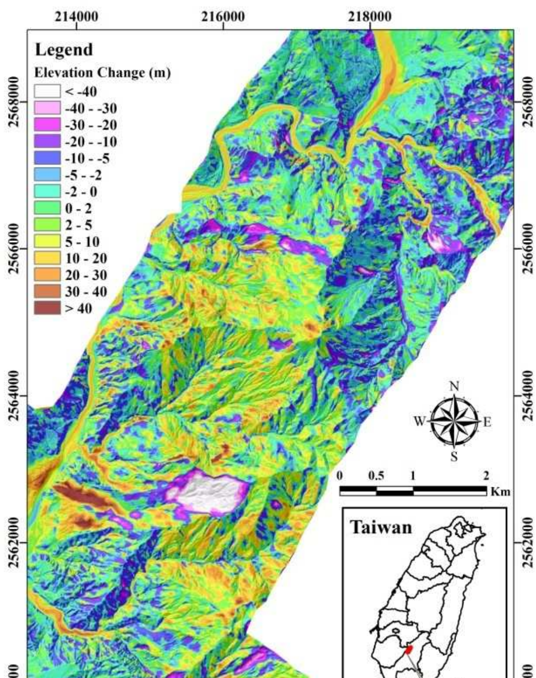

Figure 3: The Elevation Change Affected by Typhoon Morakot at the Chishan Watershed, Southern Taiwan

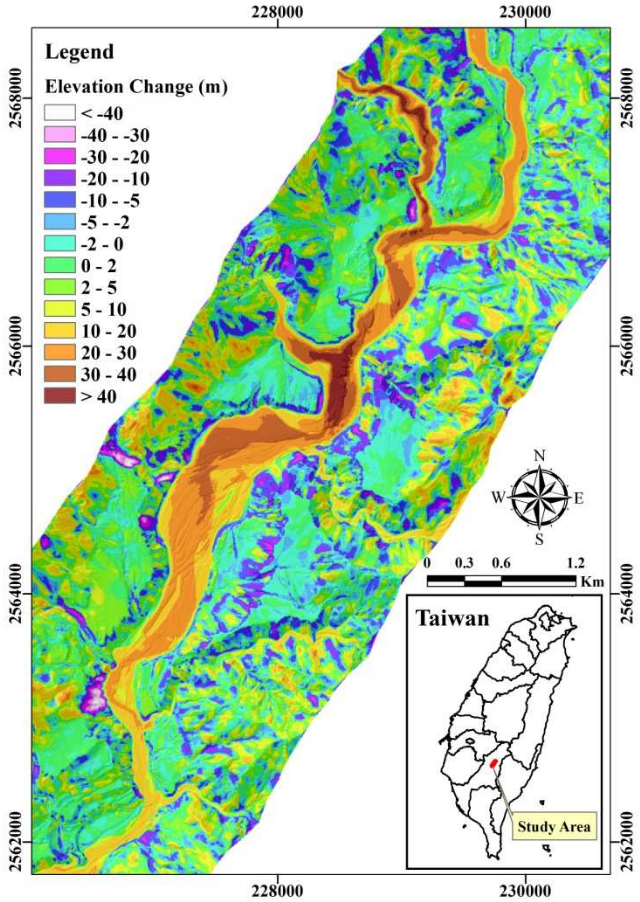

Figure 4: The Elevation Change Affected by Typhoon Morakot at the Laonong Watershed, Southern Taiwan

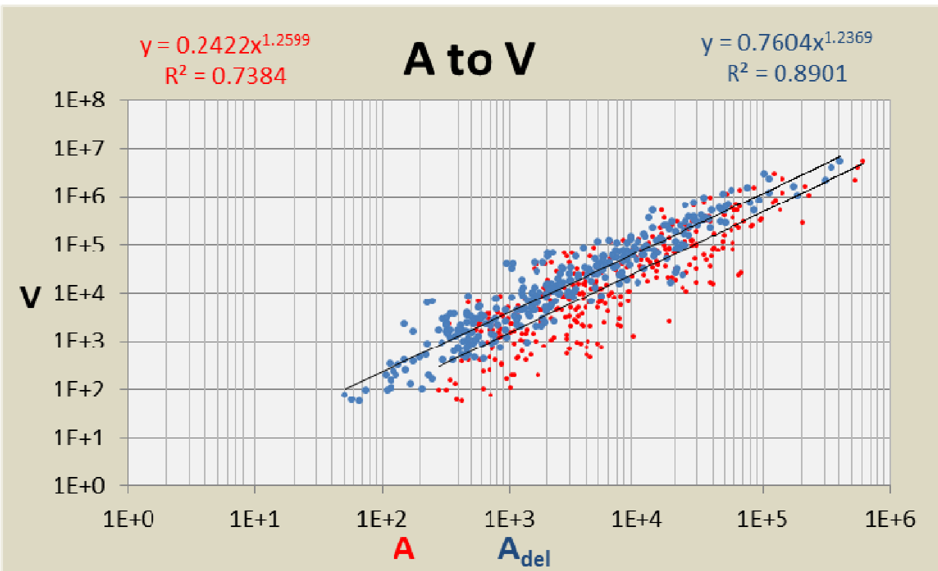

Figure 5: Regression Trends of the Landslide Volume and Area Relationship. Landslide Volume Plots with Surficial Areas (Red Dots and Horizontal Projection Areas (Blue Dots)

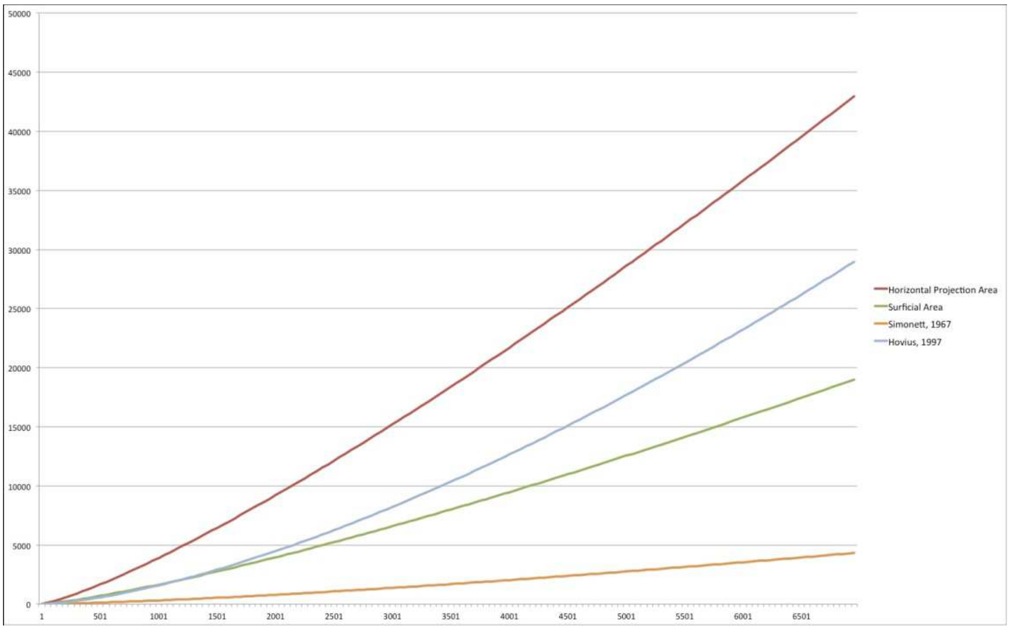

Figure 6: Calculated Landslide Volume from Surficial Areas (Green Line) and Horizontal Projection Areas (Red Line) Via Empirical Formula of this Study to other Statics Results

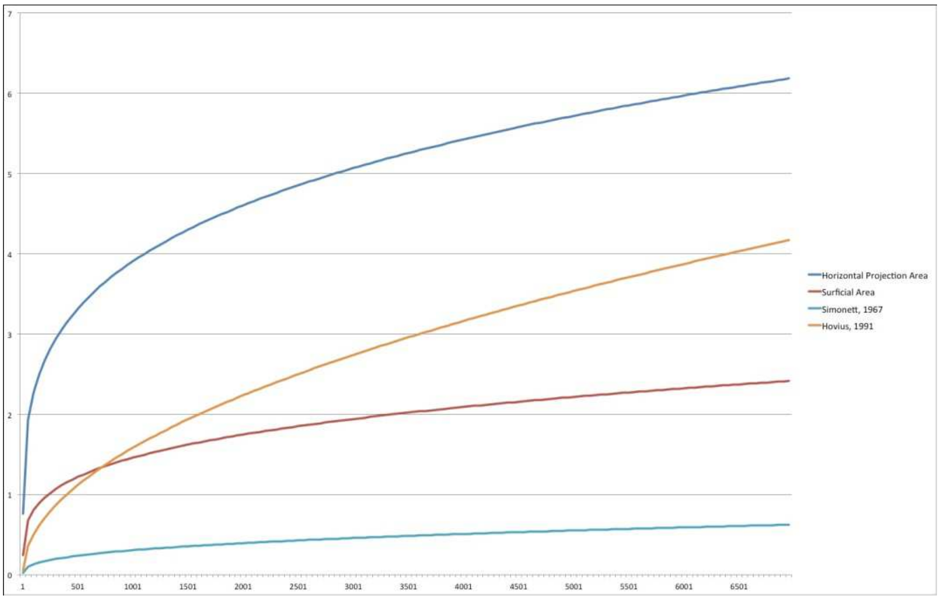

Figure 7: Calculated Average Landslide Depth from Surficial Areas (Red Line) and Horizontal Projection Areas (Blue Line) Via Empirical Formula of this Study to Other Statics Results

RESULTS AND DISCUSSIONS

There are two A-to-V equations established in this study, they are $V=0.2422A^{1.2599}$, ($R^2=0.7384$) and $V=0.7604A^{1.2369}$ ($R^2=0.8901$) via various definition of area. Most of the empirical method to estimate the volume change of landslide is to get the information of area first. Eventually the remote sensing imagery is the best choice for the task, for its fast efficiency and less cost. Remote sensing images could be gathered few days after the event, but not the case for stereo pairs or LiDAR that is essential to generate the post-event DEM. As the consequences, there is not fundamental data to

perform the image orthorectification then using the surficial areas of landslide remain as sole choice. The size of marked area is highly vulnerable to the terrain slope, aspect of slope and the line of sight from slope to the sensor. This condition explains the low R^2value at data calculated base upon surficial area; meanwhile the data from horizontal projection area offers less perturbation. Time span for normal landslide analysis is usually longer than few months, limit by the not so often landslide events or remote sensing image coverage. Therefore, the spatial distribution of these marked landslides become a result of joint effect from several rainfall or combination of earthquake effect. Such kind of phenomenon is simplified as single mechanism to investigate the possible cause and its factors in triggering the landslide, therefore inconsistence or large degree of bias within such drawn conclusion is often found. Typhoon Morakot brought almost 3,000 mm precipitation within 72 hours at southern Taiwan, and the newly triggered landslide is captured by FormoSat-2 optical satellite few days after the event. We analysis 393 cases of landslide induced by this single heavy rainfall event, and precise post-event LiDAR DEM is utilized to establish an empirical formula in determine the landslide volume via horizontal projection volume. Landslide area treated as horizontal projected offer higher degree of data consistency than regular surficial area (R^2valueclose to 0.9).

CONCLUSIONS

By compare to other statics volume estimation via different data set, we found the heavy rainfall of typhoon Morakot induced much more events and also scale of landslides. This could be found from high coefficients of 0.7604 at this study to the values of 0.024~0.05 among others. This finding could be served as an effective tool to distinguish the individual effect of single heavy rainfall event throughout the regular composite finding. Neither the method of surficial area nor the previous proposed formula could derives a averaged depth greater than 5 m for this testing cases, and there are several deep seated landslides found within this dataset (shown as area of color pink, purple to white at Figure 3 and 4). This regressed formula could account for the particular behavior of landslide induced by a single heavy rainfall. While remote sensed images gathered across a rainfall event, the changed area of induced landslide could be found. The volume of individual landslide can be estimated by the SIS method by Wang et al. [2014], therefore the associated factors in affecting the rupture of landslide with such induce rainfall should be clearly defined within tolerance error.

REFERENCES

1. Arnadottir, T., H. Geirsson, and P. Einarsson (2004), Coseismic stress changes and crustal deformation on the Reykjanes Peninsula due to triggered earthquakes on 17 June 2000, *Journal of Geophysical Research*, *109*, B09307.

2. Glade, T. (1998), Establishing the frequency and magnitude of landslide-triggering rainstorm events in New Zealand, *Environmental Geology*, *35*(2-3), 160-174, doi:10.1007/s002540050302.

3. Guzzetti, F., A. Carrara, M. Cardinali, and P. Reichenbach (1999), Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy, *Geomorphology*, *31*(1–4), 181-216, doi:http://dx.doi.org/10.1016/S0169-555X(99)00078-1.

4. Hovius N, Stark CP, Allen PA. (1997), Sediment flux from a mountain belt derived by landslide mapping. Geology 25: 231–234.

5. Petley, D. N., and R. J. Allison (1997), The mechanics of deep-seated landslides, *Earth Surface Processes and*

Landforms, *22*(8), 747-758, doi:10.1002/(SICI)1096-9837(199708)22:8<747::AID-ESP767>3.0.CO;2-#.

6. Simonett DS. (1967), Landslide distribution and earthquakes in the Bewani and Torricelli Mountains, New Guinea. In Landform Studies from Australia and New Guinea, Jennings JN, Mabbutt JA (eds). Cambridge University Press: Cambridge; 64–84.

7. Wang, T.-S., T.-T. Yu, S.-T. Lee, W.-F. Peng, W.-L. Lin, and P.-L. Li (2014), MATLAB code to estimate landslide volume from single remote sensed image using genetic algorithm and imagery similarity measurement, *Computers & Geosciences*, *70*(0), 238-247, doi:http://dx.doi.org/10.1016/j.cageo.2014.06.004.